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THE APPLICATION OF IMAGE PROCESSING FOR SECURITY SURVEILLANCE

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Abstract

In the world of security surveillance, new and improved technologies are constantly being invented to ensure the safety of citizens. Closed-circuit television (CCTV) cameras are commonly used to detect intrusions on a premise by monitoring the perimeter around the compound of a building. However, in low-light conditions, detection of intruders is a challenge as conventional digital cameras may not be able to detect and identify the culprit accurately. Occasionally, alarm detectors are falsely triggered when heat signatures of animals are encountered. The guards would then be deployed to the false alarm, leading to a waste of time and energy of authorities in charge. Therefore, a security surveillance system using thermal camera is proposed. By using thermal imaging, the heat patterns of an intruder are clearly seen even in the dark, making it easier to detect their presence. First, based on the thermal levels obtained in the image, objects within the mammal heat range are segmented. Next, the segmented image is binarized before a bounding box is automatically drawn around the intruder. The ratio of the height over the width of each box is then calculated and finally, based on the ratio value, the intruder is determined to be a human or wildlife. This approach offers a simple and effective solution to detect an intruder in the dark and highlights the potential of the method to enhance the accuracy of security measures in such settings.

Keywords: Surveillance system, Thermal image.

1. Introduction

With the advancement of technology and increase in manufacturing demand, the size of factories is getting bigger and are usually built in remote areas. However, this opens up cost concerns in the security department since a large area would need many guards on duty to patrol. To help reduce the number of guards, cameras can be used to monitor the surroundings, and a security guard will be tasked with observing the videos captured.

Although this can help reduce the number of guards to secure the whole area, it is a time-consuming task and is prone to human error. Besides that, intruders in the shadows or who are beyond the perimeter hiding in the dark would be difficult to detect. Therefore, an alternative from using closed-circuit television (CCTV) cameras is to use thermal cameras which can detect heat signatures in the dark.

Thermal imaging cameras were developed in the 1950s [1] and since then, technologies and new advancements has led to newer versions of thermal imaging cameras. The primary goal of this camera is to be utilised in the military. After the upgrades, the camera became more portable and affordable. Later, it got commercialized to the public and served various purposes besides military use such as electrical inspection, agriculture usage, automotive industries, and so on. It was even used for security and surveillance purposes as it could detect intruders in the dark based on their body heat. Thermal imaging cameras was one of the best tools to be utilised in low-light conditions and provided covert surveillance without alerting the intruders. How it functions is that warmer objects would be displayed in bright yellow or orange colour whereas cooler objects would be displayed in blue or purple colour [2].

However, usage of thermal imaging camera has its challenges when it comes to detecting intruders in the dark. Since thermal cameras pick up objects based on their body heat, any mammal around the vicinity of the factory will be detected. Therefore, an existing authority personnel member must always be present at the scene to investigate the presence of intruders to avoid mistaking a wildlife animal as a human intruder. This can potentially lead to exhaustion of authority personnels and misinterpretation of intruders.

Factories that consist of hazardous environment also has thermal imaging cameras with deep learning features or deep neural networks installed [3] which can easily detect intruders in the dark. However, not all factories could afford high-end surveillance system with top notch detection features. To solve this issue for certain factories, extensive research has been conducted to develop an image processing system that could be affordable, simple and easy-to-use to detect intruders as well as identify the subjects in low-light environments.

The goal of this research is to implement thermal image processing to detect the presence of intruders and identify the subject in low-light conditions at factory areas as a form of security surveillance. By analysing the body temperature of intruders and the orientation of subject, the system aims to ensure that the presence of intruders is not falsely detected. This is since most human intruders are vertically oriented whereas most animals are horizontally oriented. Therefore, factories are safe from unexpected intrusions and authority personnels are only sent to investigate the scene when deemed necessary, saving time and energy.

There are multiple research papers done to investigate the issue of detecting intruders and identifying the subject. Several methods were proposed to solve this problem such as the use of deep learning algorithms, machine learning algorithms, artificial intelligence (AI) and other forms of algorithms. However, there is presence of research gaps which allows improvement to be made to simplify and enhance the existing techniques.

Optical surveillance cameras were mostly proposed previously for security purposes. Sahay et al. [4] uses the Spatio-Temporal (ST) technique to extract features for classification purpose, Waddenkery et al. [5] uses the video summarization (VSUMM) technique and Yang et al. [6] uses the two-stream fusion algorithm. However, due to the optical cameras being unable to detect intruders in the dark, thermal cameras became an option to solve that issue.

Kim et al. [7] proposed utilizing thermal cameras to detect intruders using a system known as the Intelligent Intrusion Detection System (IIDS). In the system, a deep learning algorithm was used, called Convolutional Neural Network (CNN). It was used to determine the presence of the intruder in low-light conditions. Long-Term Recurrent Convolutional Network (LRCN) was used to analyse the behaviour patterns of the intruder. Like another method proposed by Dangle et al. [8], thermal cameras were also utilized to detect pedestrians based on the CNN model. It dived into the thermal images and converted it to Red Green Blue (RGB) representation for image colorization purposes. Then, it passed through another process using pre-trained You Only Look Once (YOLOv5) architecture to detect the pedestrians in the dark. It produced a test accuracy of about 92%.

Ding et al. [9] proposed tracking humans in the airport using a thermal camera when an airport apron is worn at the airport runway. The use of Infrared Individual Apron Action (IIAA) dataset in the system is to recognize the action of the human through the thermal camera such as climbing on the plane or hiding underneath the plane. A target tracking algorithm was also used to detect the movement of humans. The test accuracy for action recognition was 87%.

There was also a different method of approaching the issue, which was proposed by Wong et al. [10]. A thermal imaging system were installed around the swimming pool to detect any intruders trying to swim without permission or interfering with the pool. An algorithm of head detection by measuring the dimensions of a human head was utilized to detect the presence of intruders. The test accuracy of the intruder detection method was about 96%.

Multiple algorithms and deep learning methods were utilized to determine the presence of intruders. Those approaches indeed provided decent research results with high accuracy. However, there are a few research gaps where improvement can be made. Mainly, most research articles talked about using various method to detect the presence of intruders, but to differentiate the identity of the subject is rarely elaborated.

This is important as detecting the wrong subject could lead to false alarms and inaccuracies. For example, authority personnels will be alerted if there is a presence of something moving, only to realize that it was just an animal instead of an intruder. Therefore, the identification of subject in low-light conditions will be examined in this research paper. This will ease the burdens of authority personnels and save the time and cost produced.

2. Research Methods

2.1. Project overview

The purpose of this research paper is to detect the presence of intruders in low-light conditions at factory areas and identify if the subject is a human or an animal. The research can be summarized into a simple flowchart as shown in Fig. 1.

Based on Fig. 1, the research project was done by first undergoing the video acquisition. It involves having a video captured by the thermal imaging camera installed at the factory area during nighttime. The video is then sent for processing through the system. To enable the object segmentation to be effective, each frame from the video gets changed from RGB to Hue Saturation Value (HSV) colour space. Then, subject detection is accomplished by thresholding the HSV channels, which produces a form of binary image that indicates the prospective intruders.

Following the feature extraction and morphological processing, the binary image will be refined by taking out unnecessary noise and irrelevant small, heated objects. The binary image is next placed into object classification, which labels and categorizes associated subjects as either human or animal based on the ratio aspects. Later, each frame will have a bounding box annotated onto the moving subjects along with a label, and the processed frames are combined into a video for output that clearly displays the detection of intruder and identification of subject. It ensures that intruders are accurately and efficiently identified even in low-light settings.

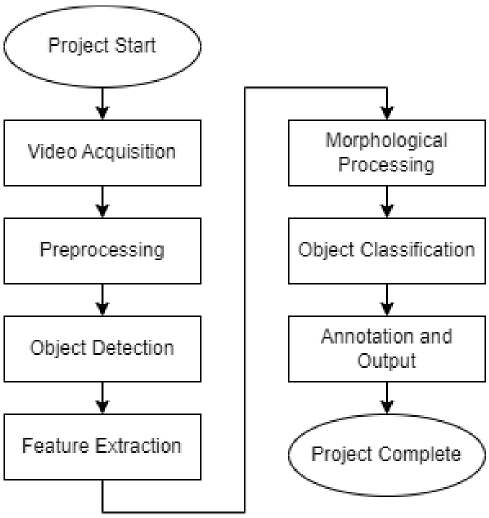

Fig. 1. Flowchart of the proposed method.

2.2. Video acquisition

A Mileseey TR160i thermal imager camera, connected to a mobile phone, was utilized to record video data, as shown in Fig. 2. These thermal cameras are primarily effective in low-light or dark conditions, allowing the footage to be processed in the system and have the presence of intruders detected. The file of the video is subsequently imported into the system for further processing.

Fig. 2. TR160i thermal imager camera.

2.3. Preprocessing

The difference of classification between a subject and the background is depicted based on the heat temperature. Yellow or orange would indicate that there is a presence of something living whereas blue or purple would indicate the background. Since blue and purple are colder regions which are not needed, it can be removed using the threshold adjuster. Therefore, a temperature range of 34.3 °C to 38.7 °C is the benchmark as shown in Fig. 3.

Through the video, each frame of its red, green, blue (RGB) is changed to hue, saturation, value (HSV) colour space. The purpose of having it changed to HSV is so that it separates the colour information (hue) from the intensity information (value). Hence, this would be helpful in low-light conditions. The change from RGB to HSV is done using the nonlinear transformation equations, as shown in Eqs. (1)-(3).

$$H = a\tan 2\left[\sqrt{3}(G - B), 2R - G - B\right] \tag{1}$$

$$S = 1 - \frac{3}{R+G+B}\min(R, G, B) \tag{2}$$

$$V = \frac{1}{3}(R + G + B) \tag{3}$$

These transformations would allow the object segmentation to be more constructive based on the colour characteristics.

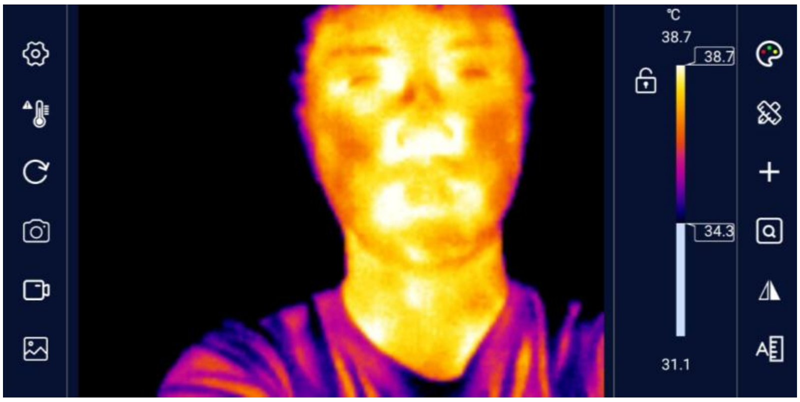

Fig. 3. Thermal imager camera interface.

2.4. Object detection

Thresholding is used on the HSV channels to generate a binary image that identifies possible intruders. To separate the objects from the background, specific hue, saturation, and value criteria are established. It can be calculated using Eq. (4).

$$binaryImage(x,y) = \begin{cases} 1 & if\ HSV(x,y) \in threshold\ range \\ 0 & otherwise \end{cases} \quad (4)$$

2.5. Feature extraction and morphological processing

The morphological operations are done onto the binary image with the sole purpose of removing the unnecessary noise and small irrelevant heated objects that was captured by the thermal camera. Types of operations include dilation, erosion, opening and closing, as shown in Eq. (5)-(8). These methods improve the binary image by making recognized objects more cohesive and distinct. The morphological operations are established utilizing the structuring elements, S:

$$Dilation: (A \oplus S)(x,y) = \max_{(i,j)\in S} A(x-i, y-j) \quad (5)$$

$$Erosion: (A \ominus S)(x,y) = \min_{(i,j)\in S} A(x+i, y+j) \quad (6)$$

$$Opening: (A \circ S) = (A \ominus S) \oplus S \quad (7)$$

$$Closing: (A \bullet S) = (A \oplus S) \ominus S \quad (8)$$

2.6. Object classification

The components in the binary image produced by the system which are connected are properly labelled, and the bounding boxes are automatically generated. The bounding boxes that are evaluated follow the assigned aspect ratio to identify the subject as either a human or an animal. When the aspect ratios of the bounding box are aligned to the predefined range where the height is longer than the width, it will be categorized as humans, whereas anything else outside the range is deemed as animals. Adding on, if there are parts of the bounding boxes that are adjacent to one another, it will be merged to represent the same object, primarily for the case of humans. As for the aspect ratio, it is calculated using Eq. (9).

$$Aspect\ Ratio = \frac{Height}{Width} \quad (9)$$

To note, bounding boxes are merged according to the proximity criteria and relative positioning. For example, boxes above each other with similar width would be merged to represent a human since the temperature at some clothes area might be lower compared to the rest of the body.

2.7. Annotation and output

On each frame of the thermal video which has a human or an animal, bounding boxes and labels are automatically annotated to indicate the presence and movement of the subject. The tagged frames are later combined into a new video file, which visually represents the final detection and identification results. The functions in the MATLAB codes, particularly “insertShape” and “insertText” functions are utilized to draw out the bounding boxes and put in a label for those boxes on the respective frames. Then, the frames which have been successfully processed will be written to an external output video file using a "VideoWriter" object.

3. Results and Discussion

3.1. Initialization of intruder detection

The thermal video of a human with a dog was captured by the thermal camera in a low-light condition environment, as shown in Fig. 4. The video is later processed using the proposed system algorithm to detect and classify the intruder.

Fig. 4. Thermal image frame of human and dog.

3.2. Thermal to binary image

Every frame of the thermal video was processed independently. The RGB frames were converted to HSV colour space and binary masks were produced using predetermined thresholds. The pictures which were in binary form were refined using the morphological techniques, leading to the object segmentation looking clearer, as shown in Fig. 5.

Fig. 5. Binary frame of human and dog.

3.3. Tracking of bounding box

After the bounding box method is implemented, the bounding box with label follows through with the subject respectively, as shown in Fig. 6. A red box indicates a human was detected while a green box indicates an animal was detected. The result of the presence and identification of subject from a few selected frames out of the total of 78 frames is shown in Table 1 based on the labelled data from ground truth.

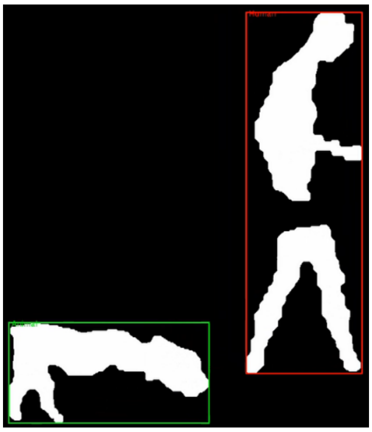

Fig. 6. Bounding box with label on respective subject.

Table 1. Result of object detection.

Frame Number	No. of Objects Detected	Human Detected	Animal Detected	Bounding Box Coordinates (x, y, width, height)
1	2	1	1	Human: (919, 308, 174, 553) Animal: (689, 766, 252, 163)
27	2	1	1	Human: (926, 300, 190, 574) Animal: (646, 777, 260, 170)
54	2	1	1	Human: (1031, 317, 177, 555) Animal: (668, 788, 307, 156)
78	2	1	1	Human: (1073, 336, 184, 553) Animal: (753, 808, 306, 146)

3.4. Overall performance

To measure the accuracy of the proposed intruder detection system, comparison was made by manually drawing a box around the human and animal using a Video

Labeler App. Thirty frames were chosen for manual labelling and after that, the coordinates of the boxes were compared with the automatically detected boxes from the proposed algorithm. With a coordinate estimation error of $\pm$10, the percentage accuracy obtained was 96.7%. Hence, it was a success to utilize the combination of HSV threshold and morphological processes to detect and identify the subjects in low-light conditions. The bounding boxes also accurately tracks the human and animal, labelling the object as “human” or “animal” correctly.

Overall, it can be said that this algorithm only requires a low-cost and portable thermal camera instead of an expensive one, making it very cost-effective. The process steps of this algorithm are also relatively efficient and appropriate for real-time uses.

4. Conclusions

In conclusion, this research paper presents a complete and systematic strategy to address the need for increased security and surveillance capabilities in low-light or dark settings by proposing a thermal image surveillance system. Using the bounding box method, it gives an opportunity for the thermal surveillance applications in factory areas to flourish. It demonstrated how converting RGB frames to HSV colour space, refining the binary images, extracting features based on aspect ratios, and identifying object to be human or animal ensures a high accuracy for detection of intruders and classification.

Moving forward, improvement in identification accuracy and integration of advanced machine learning models for complicated environments can be considered for future works. Overall, the thermal image processing system is a significant improvement in security and surveillance technology that has the potential to revolutionize nighttime monitoring and danger identification. By tackling these issues, a positive influence on society will surface and a more secure and sustainable future will be promoted.

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